Dec. 28, 1965 H. M. GEYER 3,225,626

ELECTROMECHANICAL ACTUATOR SYSTEMS

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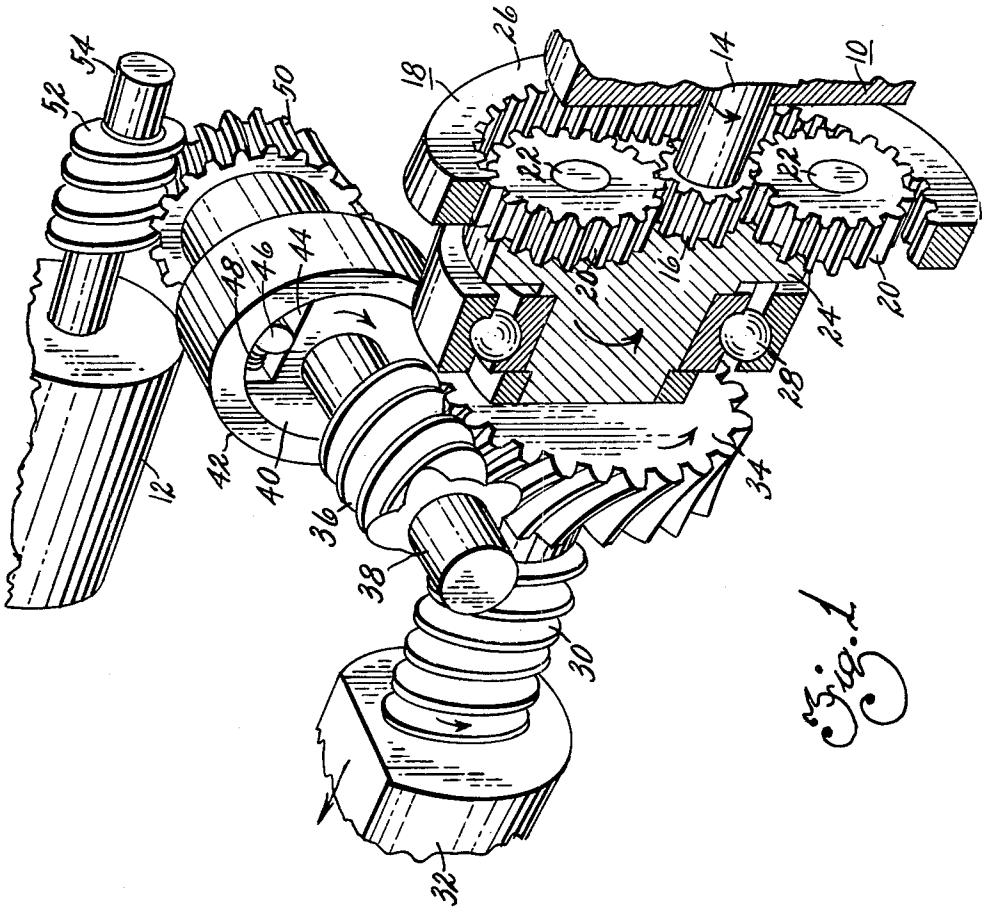


Fig. 1

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ELECTROMECHANICAL ACTUATOR SYSTEMS

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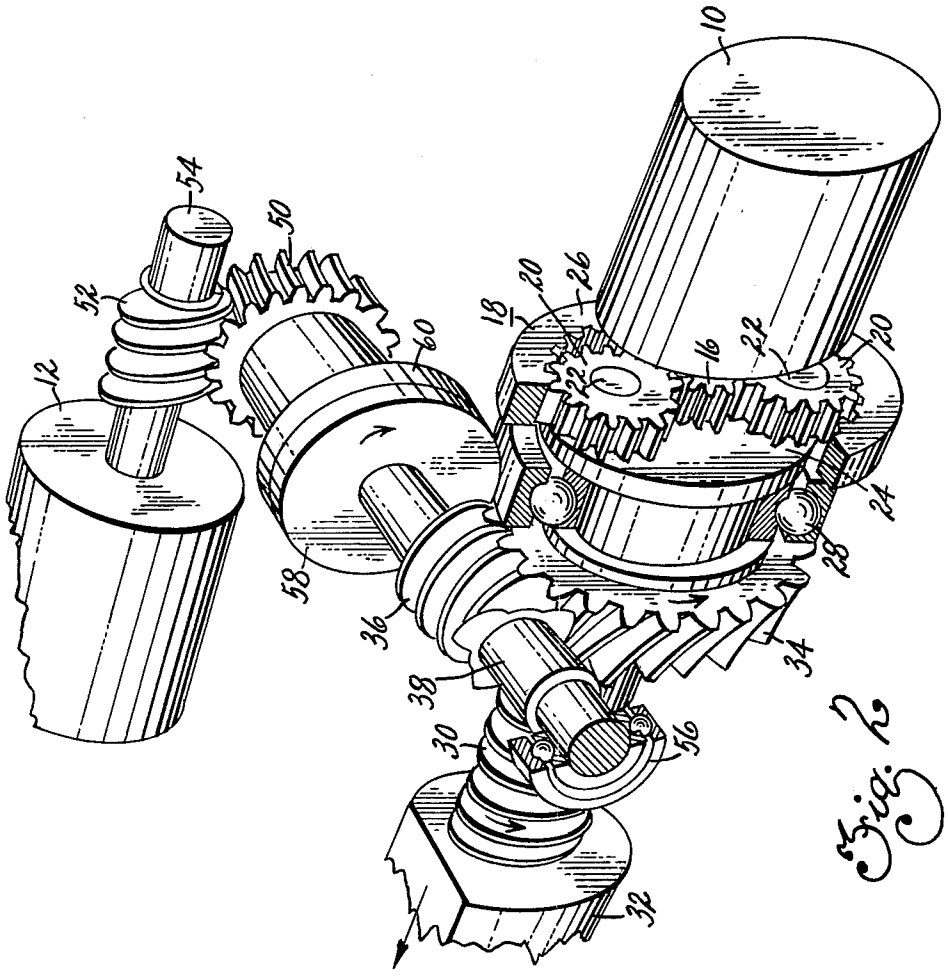


Fig. 2

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ELECTROMECHANICAL ACTUATOR SYSTEMS

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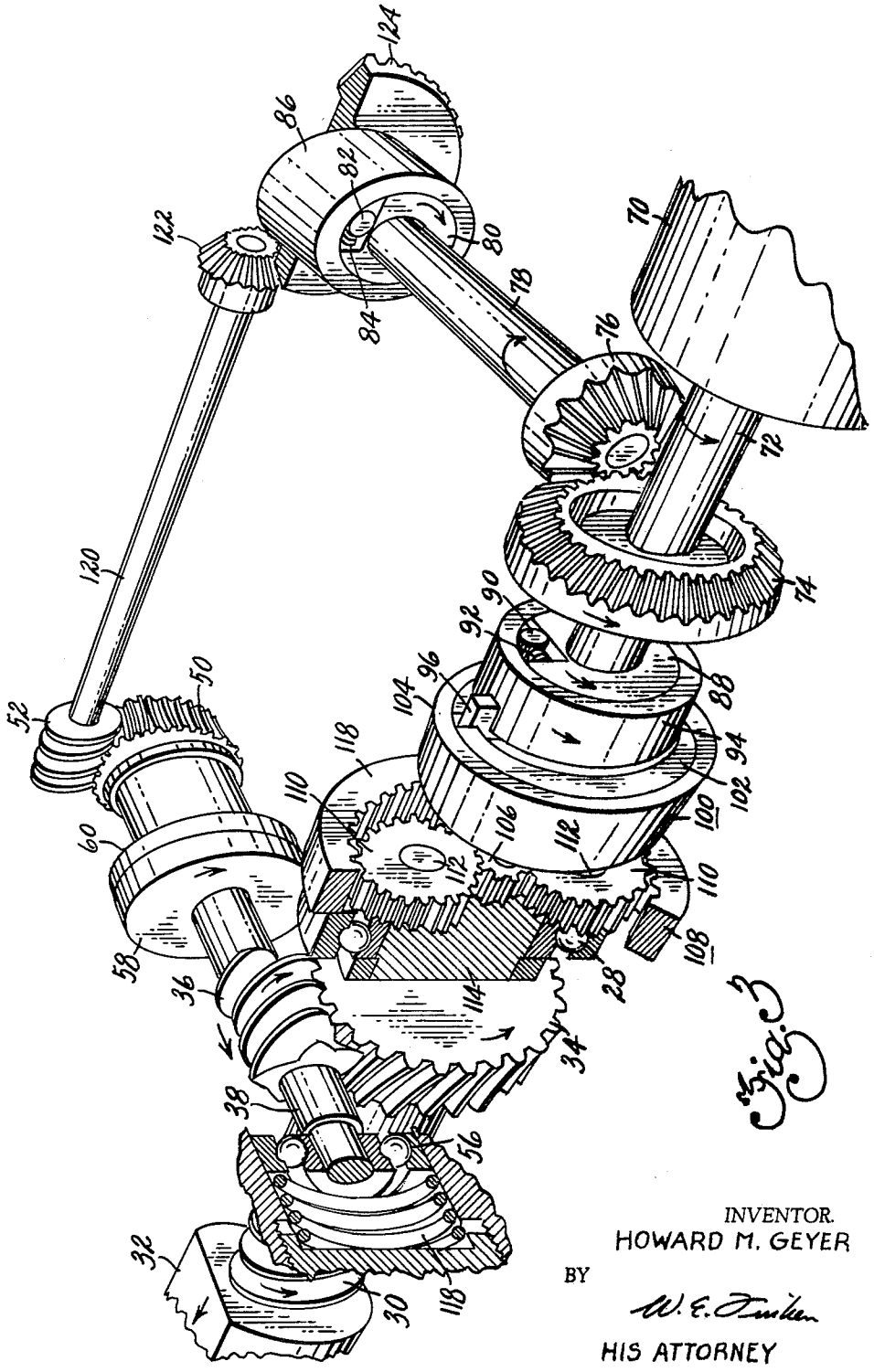


Fig. 3

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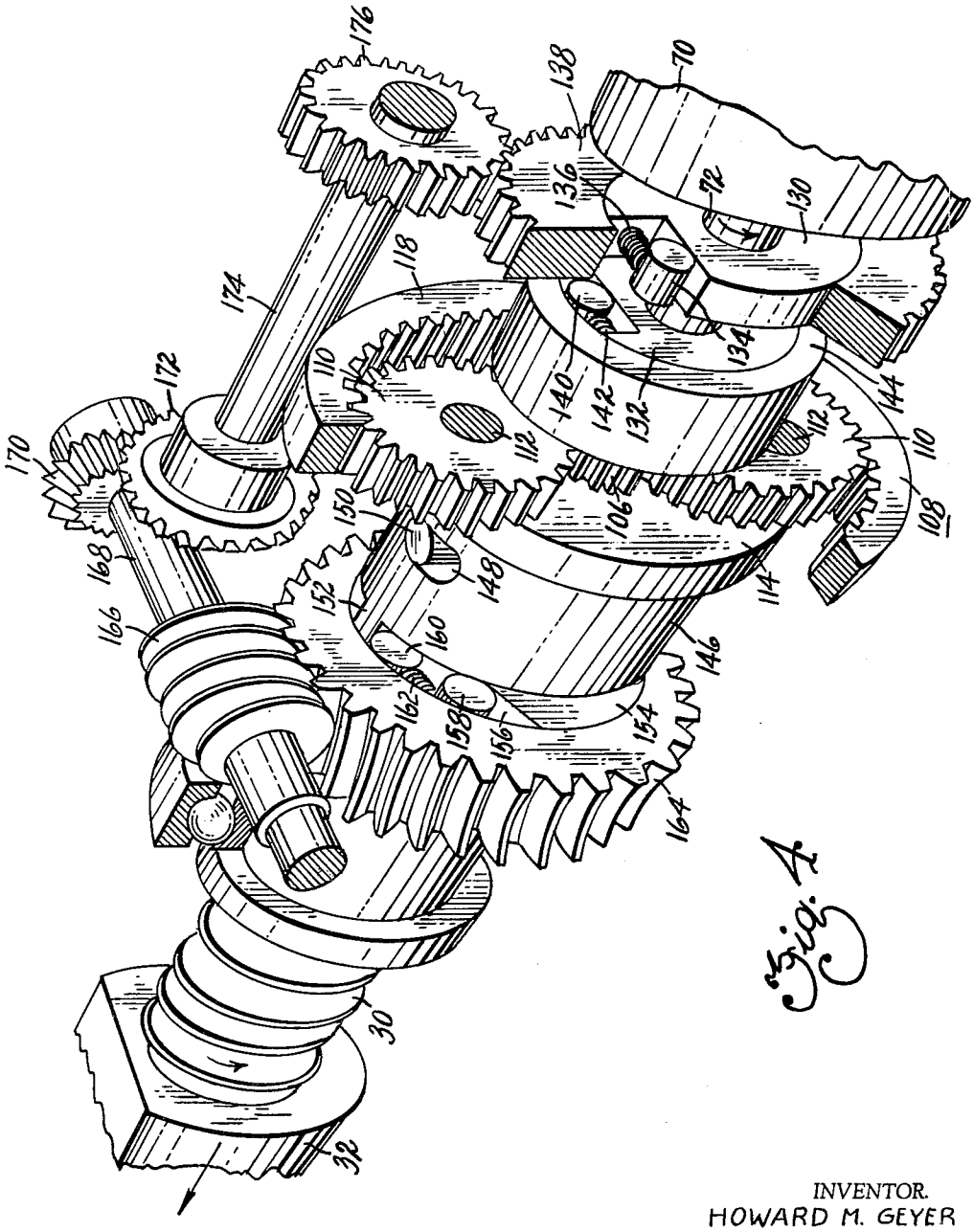


Fig. 4

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3,225,626

ELECTROMECHANICAL ACTUATOR SYSTEMS

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16 Claims. (Cl. 74—661)

This invention pertains to electromechanical actuators, and particularly to electromechanical actuators designed for handling high mass loads.

Heretofore, electromechanical aircraft actuators comprising a relatively high speed motor, a planetary gear reduction unit and a ball screw and nut assembly, which can be made relatively light in weight, have been used for operating aircraft cargo doors, landing gears, etc. The load imposed in these aircraft applications is a force load created by air or springs. On the other hand, in commercial actuator applications, the load is made up of dead weight, and on a weight loaded actuator the energy required to raise the weight must be absorbed when the weight is lowered. In other words, the energy stored in weight loaded actuators must be dissipated, and experience has shown that one of the most satisfactory ways of handling this type of mechanism is through an irreversible mechanism such as a low lead Acme screw or a worm gear train. However, one of the drawbacks of either of the latter types is that the high power required to raise the load prohibits its use in aircraft due to the inefficiency of the drive train.

The present invention relates to electromechanical actuator systems embodying the best features of both aircraft and commercial actuators for raising and lowering high inertia loads, such as those required for cargo loading and missile launching, wherein a high efficiency drive is utilized for raising the load and a low efficiency drive is used for lowering the load. Accordingly, among my objects are the provision of an electromechanical actuator for high mass loads including separate drives for raising and lowering the load; the further provision of an electromechanical actuator of the aforesaid type including a high efficiency drive for raising a high mass load and a low efficiency drive for lowering the load; the further provision of an electromechanical actuator system of the aforesaid type including separate motors for raising and lowering a high mass load; and the still further provision of an electromechanical actuator system of the aforesaid type including a single motor for raising and lowering a high mass load through different drive paths.

The aforementioned and other objects are accomplished in the present invention by utilizing a high efficiency planetary gear train in the drive path for raising the high mass load, and a relatively low efficiency worm drive in the path for lowering the high mass load. Specifically, four embodiments of the improved electromechanical actuator system are disclosed wherein two embodiments utilize separate motors for raising and lowering the load, and the preferred embodiments utilize only a single motor to both raise and lower the load through separate drive paths. The several embodiments of electromechanical actuator systems disclosed herein comprise combinations of brakes, clutches and roller types of free wheeling devices which facilitate the use of two different gear trains, or drive paths.

Further objects and advantages of the present invention will be apparent from the following description, reference being had to the accompanying drawings, wherein preferred forms of the present invention are clearly shown.

In the drawings:

FIGURE 1 is a fragmentary perspective view, partly in section and partly in elevation, depicting one embodiment of an electromechanical actuator for a high mass load utilizing two motors.

FIGURE 2 is a fragmentary perspective view, partly in section and partly in elevation, of a second embodiment utilizing two motors.

FIGURE 3 is a fragmentary perspective view, partly in elevation and partly in section, depicting a third embodiment utilizing a single motor.

FIGURE 4 is a fragmentary perspective view, partly in section and partly in elevation, of the preferred electromechanical actuator embodying a single motor for raising and lowering a high mass load through different gear trains.

With reference to FIGURE 1, an electromechanical actuator system is disclosed comprising a pair of unidirectional electric motors **10** and **12**, the motor **10** being utilized to raise a high mass load, and the motor **12** being used to lower the load. The motor **10** includes a shaft **14** drivingly connected to a sun gear **16** of a highly efficient planetary gear set **18**. The planetary gear set **18** includes planet pinions **20** journalled on stub shafts **22** attached to a carrier **24**, and a fixed ring gear **26**. The carrier **24** is journalled by a thrust ball bearing assembly **28**, and as shown, may be formed as an integral part of a reversible screw shaft **30** forming a component of a ball screw and nut assembly, including a nut **32** having threaded engagement with the screw shaft **30** through a plurality of circulating balls, not shown, such as is well known in the art. Since the nut **32** is restrained against rotation, rotation of the screw shaft will result in axial movement of the nut therealong in a direction dependent upon the direction of rotation of the screw shaft.

The direction of rotation of the motor shaft **14** for extending, or raising, the high mass load is indicated by arrows, from which it is seen that the shaft **14** rotates in a counterclockwise direction as do the carrier **24** and the screw shaft **30**. The screw shaft **30** has a worm wheel **34** attached thereto that meshes with a transversely extending worm **36** constituting a reversible worm drive. The worm **36** is attached to a shaft **38** to which a cam **40** is secured. The cam is disposed within an annulus **42** and has a cutout **44** which, with the annulus **42**, forms a cage for a roller **46** biased by a coil spring **48**, this structure constituting an over-running clutch of the roller and spring type. During extending movement of the actuator, the worm shaft **38** and the cam **40** are rotated in the clockwise direction thereby releasing the clutch such that the annulus **42** remains stationary. The annulus **42** is connected to a second worm wheel **50** meshing with a worm **52** attached to a shaft **54** of the motor **12**, constituting an irreversible worm drive for retracting the actuator with an aiding, or compression, load.

It will be apparent that when the motor **10** is energized to extend the load, the screw shaft **30** will be driven in one direction, and that the drive is highly efficient, being of the planetary gear type, whereas when the motor **12** is energized the screw shaft **30** will be rotated in the opposite direction to retract the load through the low efficiency worm gearing and the one-way over-running clutch. The load acting on the nut is a compression load and comprises a dead weight.

Referring to FIGURE 2, a second embodiment of a dual motor electromechanical acuator system is disclosed, similar numbers referring to similar parts previously described in connection with the embodiment of FIGURE **1**. Thus, in the second embodiment the electric motor **10** is connected to the screw shaft **30** through planetary gear set **18** for raising, or extending, the load attached to the nut **32**. However, in this embodiment the worm shaft **38**, which is journalled by thrust ball bearing assembly **56** has a friction clutch disc **58** attached thereto in en-

gagement with a second friction clutch disc **60** secured to the shaft of the worm wheel **50** of the irreversible worm drive. When the motor **10** is driving the screw shaft in the counterclockwise direction to extend the actuator, as indicated by the arrows, the worm **36** engaging the worm wheel **34** of the reversible worm drive acts like a rack and tends to separate the clutch discs **58** and **60** so as to interrupt the driving connection therebetween. However, when the motor **12** is energized to retract the load through worm **52** and worm wheel **50**, the torque being less than the torque required to slip the clutch discs, the clutch discs **58** and **60** will be held in engagement due to the compression load which causes the worm **36** to operate as a rack applying force to the clutch plates proportional to the load on the actuator thereby enabling rotation to be imparted to the screw shaft **30** in the direction opposite the direction indicated by the arrows. The irreversible worm gear drive must, under these conditions, absorb the energy of the load and the gear function.

In both of the two motor electromechanical actuator system embodiments of FIGURE 1 and 2, dual drive paths are provided for raising and lowering a high mass load, namely a high efficiency planetary gear drive for raising the load and a low efficiency worm drive for lowering the load. Moreover, since the load is dead weight and acting in compression, the retract motor can be relatively small since it need only supply the power to rotate the reversible worm drive and thus control the rate of lowering, or retraction.

With reference to FIGURE 3, an electromechanical actuator system having dual drive paths and employing only a single motor is disclosed. In this system, a reversible electric motor **70** has its shaft **72** attached to a bevel gear **74** which meshes with a second bevel gear **76** attached to a shaft **78** and carrying a cam **80** for a one-way over-running clutch comprising a roller **82**, a spring **84** and an annulus **86**. The shaft **72** is connected to a cam **88** of a second one-way over-running clutch comprising a roller **90**, a spring **92** and an annulus **94**. The annulus **94** is formed with a radial extending tang **96** constituting a driver for a centrifugal clutch assembly **100** of the type disclosed in Light Patent 2,747,713 which includes a split sleeve **102** and an annular housing **104**.

The housing **104** is drivingly connected to a sun gear **106** of a planetary gear set **108** having planet pinions **110** journalled on shafts **112** attached to a carrier **114**, and a fixed ring gear **118**. The carrier **114** may be integral with the screw shaft **30** and is rotatably supported by a thrust ball bearing assembly **28**. The screw shaft **30** forms a component of a ball screw and nut assembly including a nut **32** which is threadedly connected with the shaft through a plurality of circulating balls, not shown.

A worm wheel **34** is attached to the screw shaft **30**, this worm wheel **34** meshing with a worm **36** attached to a worm shaft **38** journalled by a thrust bearing **56**. The worm wheel **34** and worm **36** constitute a reversible worm drive. As in the embodiment shown in FIGURE **2**, the worm shaft **38** is connected to a clutch plate **58** engageable with a second clutch plate **60** connected to the worm wheel **50** that meshes with worm **52**, the worm wheel **50** and worm **52** being irreversible, or self-locking. In addition, the worm shaft and friction clutch plates **58** and **60** are preloaded by a spring **118**. The spring **118** maintains the clutch plates in contact and thus permits the actuator to be positively retracted even under a no load condition by the motor.

The worm **52** is attached to a shaft **120** having a bevel gear **122** meshed with a bevel gear **124** attached to the clutch housing **86**. When the motor **70** drives the shaft **72** in the counterclockwise direction as indicated by the arrows in FIGURE 3, the roller clutch **82** associated with the bevel gear **124** is disengaged whereas the roller clutch **90** associated with the centrifugal clutch **100** is engaged thus rotating the screw shaft through the efficient planetary gear set to extend the actuator. At this time the worm **36** acts as a rack to relieve the preload of spring **118** on the clutch plates **58** and **60** so that no movement is imparted to the worm wheel **50** and worm **50**.

When the motor **70** is rotated in the reverse direction, the roller clutch **82** drives its housing **86**, and hence rotation is imparted to the screw shaft in the reverse direction through bevel gear **124** and **122**, irreversible worm drive **52** and **50**, the clutch plates **58** and **60** which are held in engagement by the preloaded spring **180** and the rack effect of the worm **36**. During reverse rotation the centrifugal clutch **100** is disengaged, and the roller clutch **90** is free-wheeling.

Referring to FIGURE 4 the preferred embodiment of the electromechanical actuator system embodying dual drive paths will be described, similar reference numerals referring to similar parts previously described in connection with the embodiment shown in FIGURE 3. In this embodiment the motor **70** is connected to a pair of over-running, one-way clutch cams **130** and **132**. The cam **130** coacts with a roller **134** having a spring **136** and a housing **138**. The cam **132** coacts with a roller **140** biased by a spring **142** and having a housing **144** attached to the sun gear **106** of the planetary gear set **108**. In this embodiment the carrier, or spider, **114** is not integral with the screw shaft **30**, but on the other hand, is formed with a skirt **146** having an elongate, peripheral, arcuate slot **148** therein receiving a pin **150** attached to the screw shaft **30**. The skirt **146** is formed with an axially extending brake released tang **152** constituting a component of a roller no-back, or double acting brake, including a cam **154** attached to the screw shaft having a flat **156** with a pair of spaced rollers **158** and **160** biased apart by a coil spring **162**. The rollers coact with the rim of worm wheel **164** that meshes with worm **166**, the worm and worm wheel being irreversible. The worm is attached to a worm shaft **168** connected by bevel gears **170** and **172** with a shaft **174** having a spur gear **176** meshing with the gear **138**.

When the motor shaft **72** is rotated in the counterclockwise direction as indicated in FIGURE 4, the roller clutch **134** is released while the roller clutch **140** is engaged so as to rotate the screw shaft **30** through the high efficient planetary gear set which is then driven through the drive pin **150** on the skirt **146**. At this time the drive roller **160** is released so that the worm gear **164** remains stationary.

When the direction of rotation of the motor is reversed, the roller clutch **134** is engaged while the roller clutch **140** is released such that rotation is imparted to gear **176**, and thence through shaft **174** and bevel gears **172** and **170** to the worm shaft **168**. This will result in driving the screw shaft **30** in the clockwise direction through irreversible worms **166** and worm wheel **164** through the engaged retract drive roller **160** which controls the rate of actuator retraction and lowering of the high mass load in accordance with the speed of the motor. The load torque is not transmitted through the drive pin **150** during retraction, and the load carrying, or brake roller **158** is never released.

While the embodiments of the invention as herein disclosed constitute preferred forms, it is to be understood that other forms might be adopted.

What is claimed is as follows:

1. An electromechanical actuator system for high mass loads comprising, a screw and nut actuator and dual drive paths for extending and retracting said actuator, one of said drive paths including a high efficiency reduction unit operatively connected with said actuator and the other of said drive paths including a low efficiency irreversible reduction unit operatively connected with said actuator.

2. The electromechanical actuator system set forth in claim **1** wherein said high efficiency unit comprises a planetary gear reduction.

3. The electromechanical actuator system set forth in claim 1 wherein said low efficiency unit comprises an irreversible worm drive reduction.

4. The electromechanical actuator system set forth in claim 1 wherein said high efficiency unit comprises a planetary gear reduction, and wherein said low efficiency unit comprises an irreversible worm drive reduction.

5. An electromechanical actuator system for high mass loads comprising, a screw and nut actuator including a rotatable screw shaft and an axially movable non-rotatable nut, electric motor means for rotating said screw shaft in opposite directions to extend and retract said actuator, and separate drive paths operatively interconnecting said electric motor means and said screw shaft for extending and retracting said actuator, said separate drive paths including a high efficiency reduction unit operatively connected with said screw shaft for extending said actuator and a low efficiency reduction irreversible unit operatively connected with said screw shaft for retracting said actuator.

6. The electromechanical actuator system set forth in claim 5 wherein said electric motor means comprises two unidirectional electric motors.

7. The electromechanical actuator system set forth in claim 6 wherein said high efficiency reduction unit comprises a planetary gear set operatively connected between said screw shaft and one of said motors, and wherein said irreversible low efficiency reduction unit comprises a reversible worm and worm wheel drivingly connected with said screw shaft, an irreversible worm and worm wheel drivingly connected with the second motor and a one-way roller clutch operatively interconnecting said irreversible worm and worm wheel and said reversible worm and worm wheel such that said reversible worm and worm wheel free-wheels during extension of the actuator.

8. The system set forth in claim 6 wherein said high efficiency reduction unit comprises a planetary gear set operatively connected between one of said motors and said screw shaft, and wherein said low efficiency reduction unit comprises a reversible worm drivingly connected with said screw shaft, an irreversible worm drive connected with the second motor and a pair of friction clutch discs for drivingly connecting said reversible and irreversible worm drives when said second motor is energized to retract said actuator.

9. The system set forth in claim 8 wherein said reversible worm drive includes a worm wheel attached to said screw shaft, a worm meshing with said worm wheel and a worm shaft secured to said worm, said worm shaft being movable axially in opposite directions to engage and disengage said clutch discs.

10. The electromechanical actuator system set forth in claim 5 wherein said electric motor means comprises a reversible electric motor.

11. The system set forth in claim 10 wherein said high efficiency reduction unit comprises a planetary gear set connected to said screw shaft, the input to said planetary gear set comprising a centrifugally responsive clutch and a one-way roller clutch connected to said motor, and wherein said low efficiency reduction unit comprises a reversible worm drive operatively connected with said screw shaft, an irreversible worm drive, a friction clutch operative to connect and disconnect said irreversible and reversible worm drives and a one-way drive connection between said motor and said irreversible worm drive whereby rotation of said motor in one direction will extend said actuator and rotation of said motor in the opposite direction will retract said actuator.

12. The system set forth in claim 11 wherein said reversible worm drive comprises a worm wheel drivingly connected with said screw shaft, a worm meshing with said worm wheel and secured to a worm shaft, said friction clutch comprising a pair of discs, one of which is attached to said worm shaft and the other of which is drivingly connected to the worm drive, and wherein said worm shaft is axially movable and spring biased to normally engage said clutch discs, said clutch discs being separated through rack action of the worm on the worm wheel of the reversible worm drive during actuator extension and engaged during actuator retraction.

13. An electromechanical actuator system for high mass loads comprising, a screw and nut actuator including a rotatable screw shaft and a nonrotatable nut, a reversible electric motor for extending and retracting said actuator, and dual drive paths operatively interconnecting said motor and said screw shaft including a high efficiency drive path operatively connected with said screw shaft for extending said actuator and a low efficiency drive path operatively connected with said screw shaft for retracting said actuator, said high efficiency drive path comprising a one-way clutch, a planetary gear set and a roller no-back, said low efficiency drive path comprising a one-way clutch, an irreversible worm drive and said roller no-back.

14. The system set forth in claim 13 wherein said one-way clutches are of the roller type, and include coaxially arranged cams.

15. The system set forth in claim 13 wherein said roller no-back comprises a cam having a single flat thereon, a pair of rollers arranged on said flat and biased apart by spring means, an annulus coaxial with said cam and encompassing said rollers and said cam and a release tang, said release tang being integral with an annulus attached to the output of said planetary gear set and having an arcuate peripheral slot therein, and a drive pin attached to the screw shaft and extending through said slot whereby rotation of said motor in one direction will release said no-back to rotate the screw shaft in one direction through said drive pin, and rotation of the motor in the opposite direction will drive said screw shaft in the opposite direction through said irreversible worm drive with the no-back engaged.

16. The system set forth in claim 15 wherein one of the rollers of the no-back constitutes a drive roller which is released during actuator extension and engaged during actuator retraction, and the other roller comprises a braking roller which is always engaged.

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